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San Antonio, Texas
Promoting Readiness through Environmental Stewardship

Bioremediation of Solvent Sites Using Direct Hydrogen Delivery

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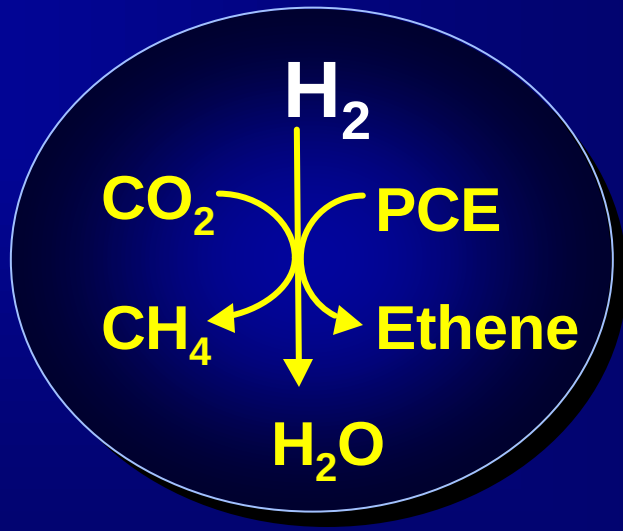
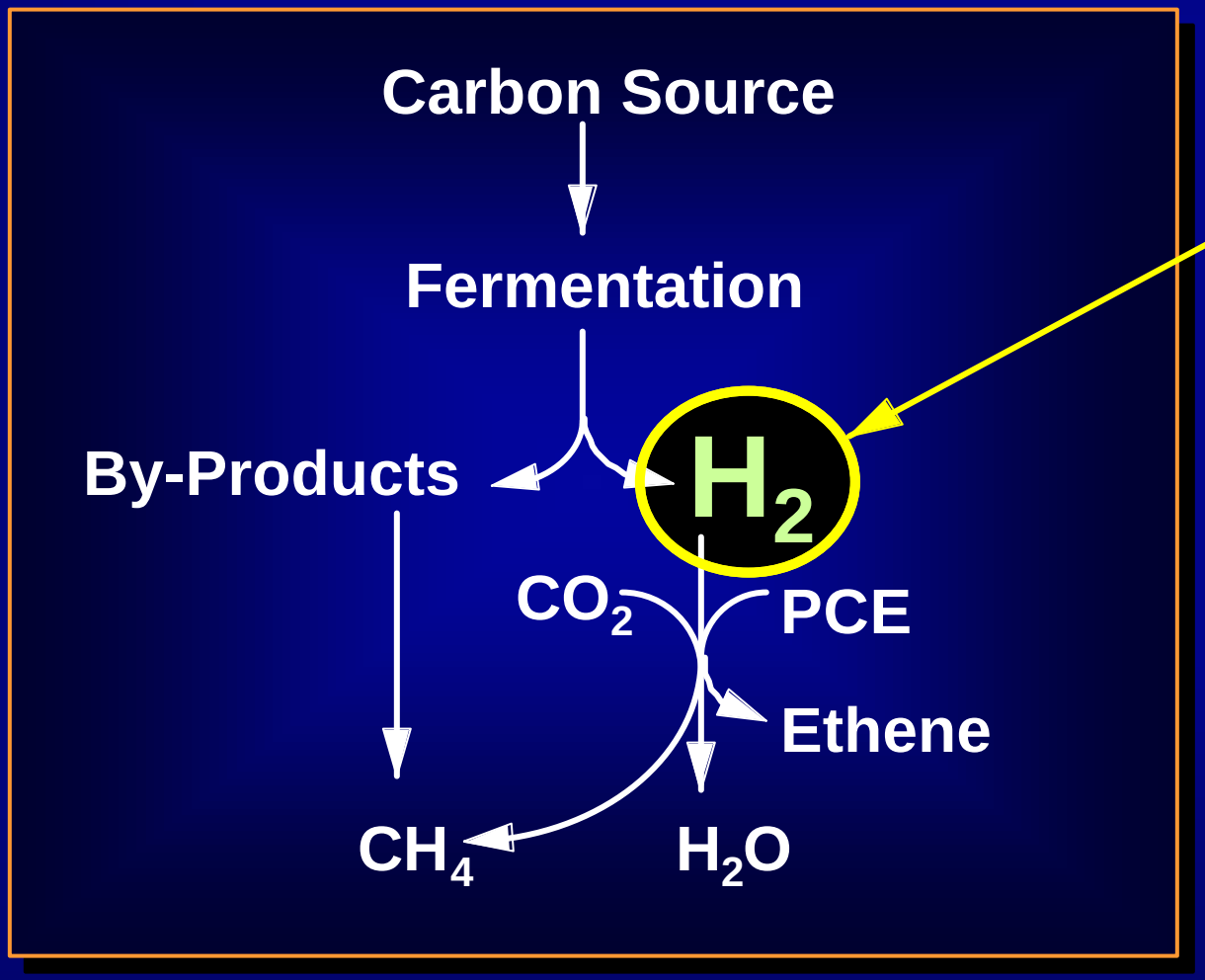


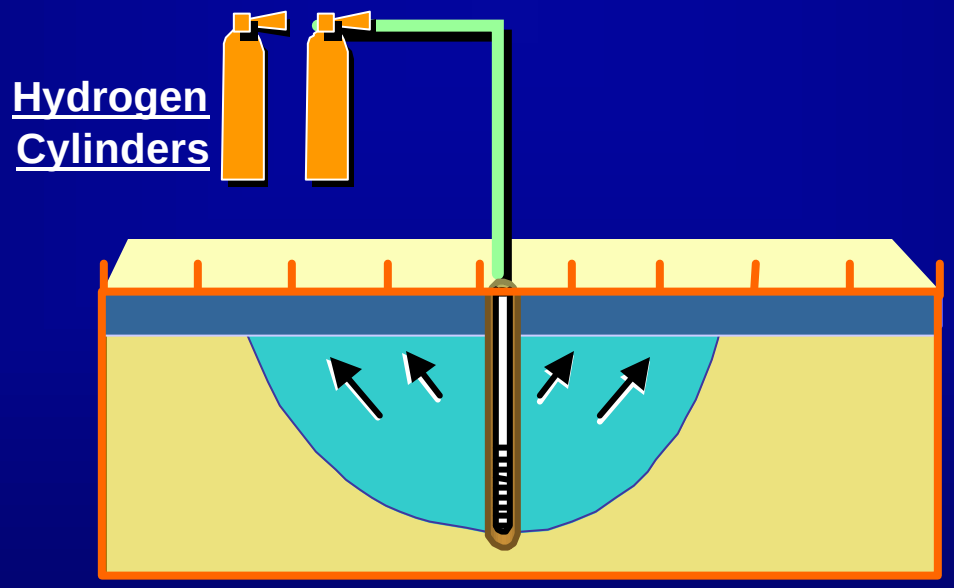
Biodegradation of Chlorinated Solvents



Electron Donor; Limits Biodeg.

DELIVERY APPROACH 1:

LOW-VOLUME PULSED BIOSPARGING

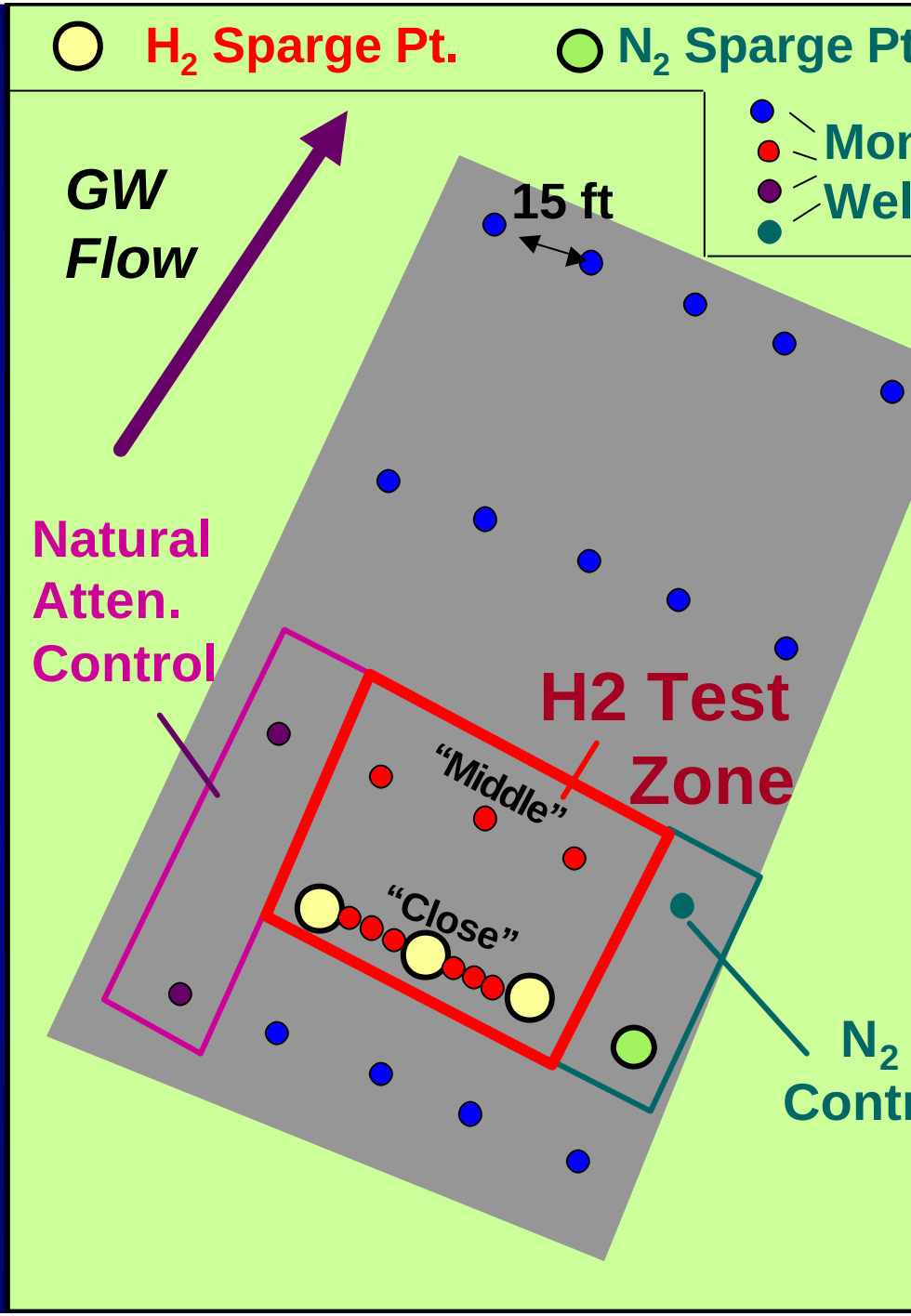


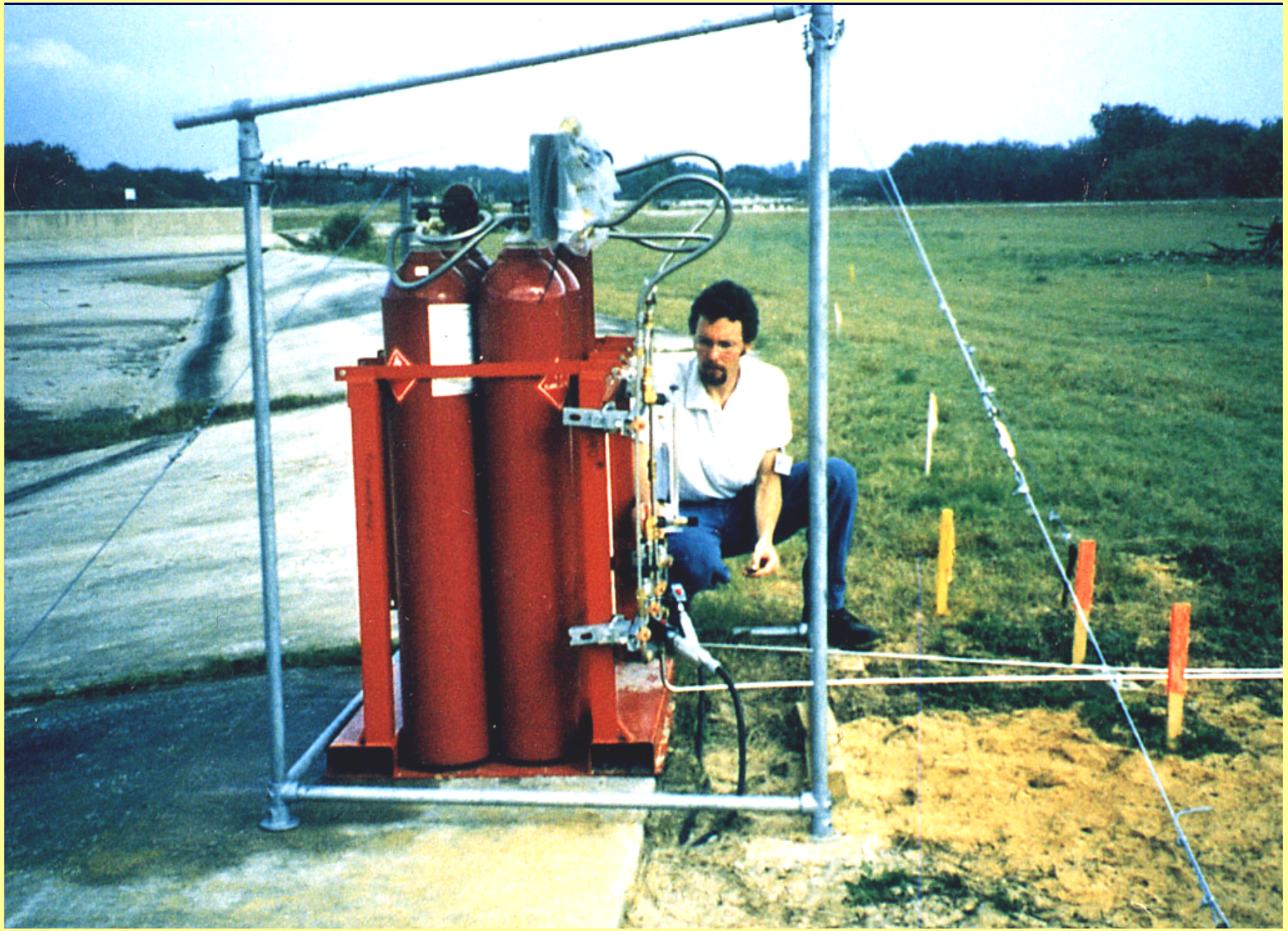
Cape Canaveral Low-Volume Pulsed Biosparge

- 4 Sparge Wells
- 6 Multi-Level Points
- 20 Other Monitoring Points

Sparging For Each Well:

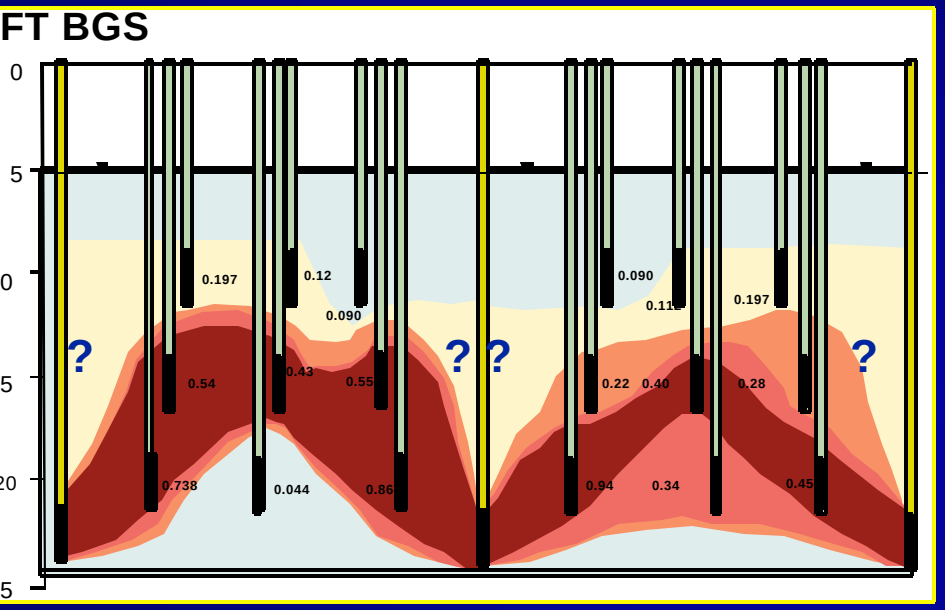
- 130 ft^3 on Day 1
- 6 ft^3 per day (Days 0-120)
- 60 ft^3 per week (Days 120+)



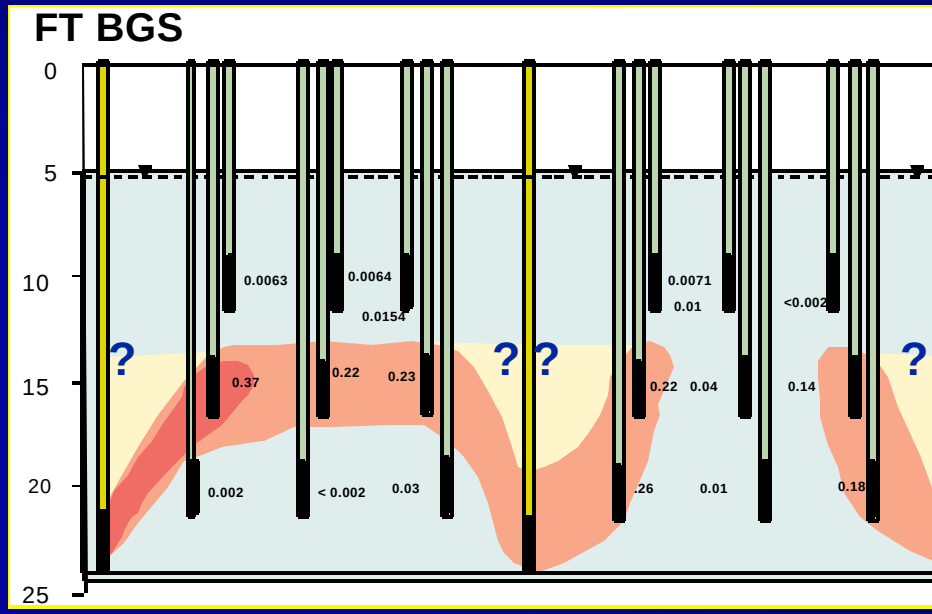


Cape Canaveral Hydrogen Biosparge

Dissolved He vs. H_2 Concentrations - 1 Yr



Dissolved Helium Tracer (no biodegradation)

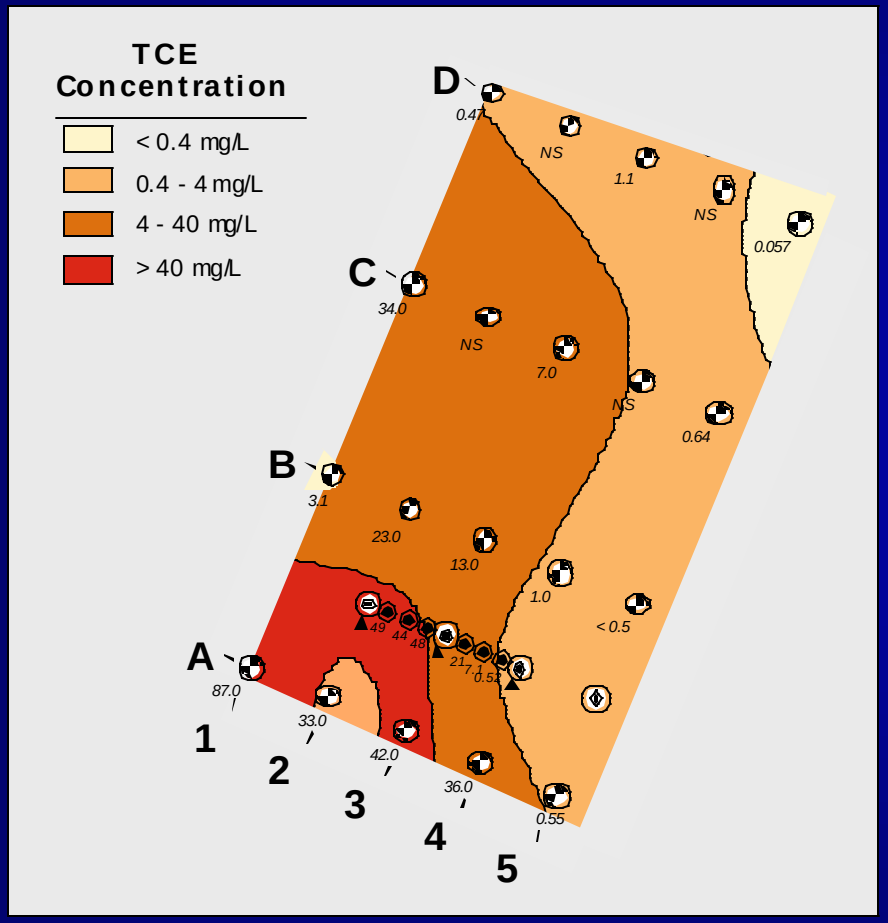


Dissolved Hydrogen (4 Days After Sparge Pulse)

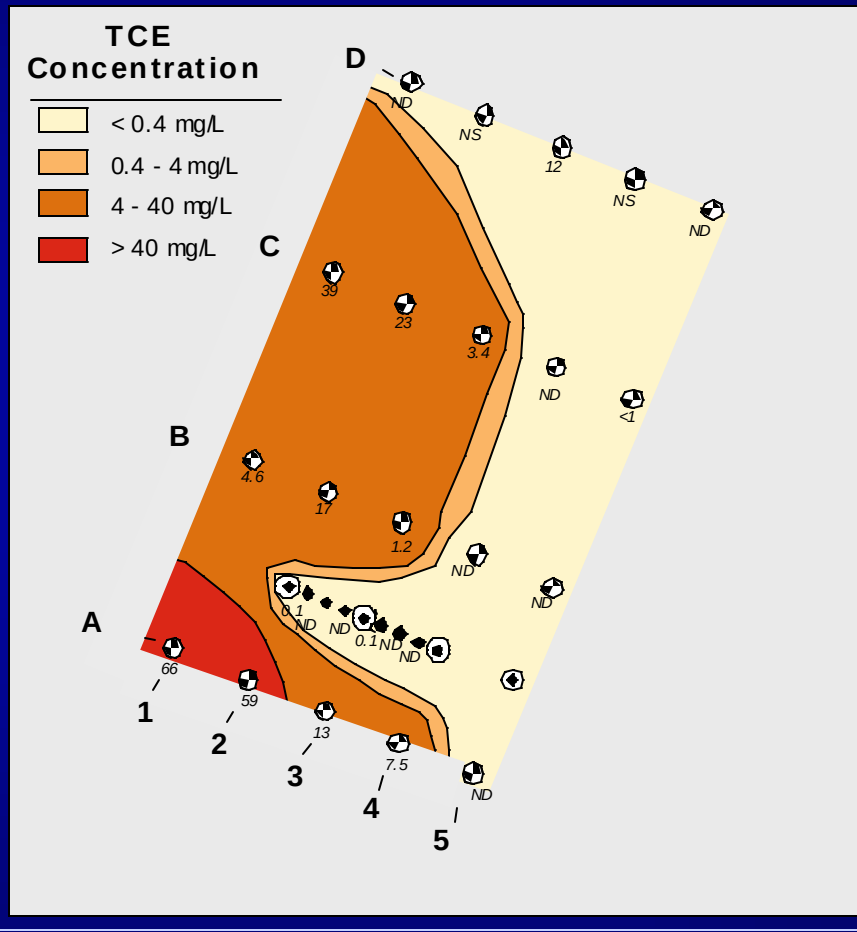
Dissolved He and H_2 Concentrations

- 0.1 - 0.2 mg/L
- 0.2 - 0.3 mg/L
- 0.3 - 0.4 mg/L
- > 0.4 mg/L

18 Month Change in TCE

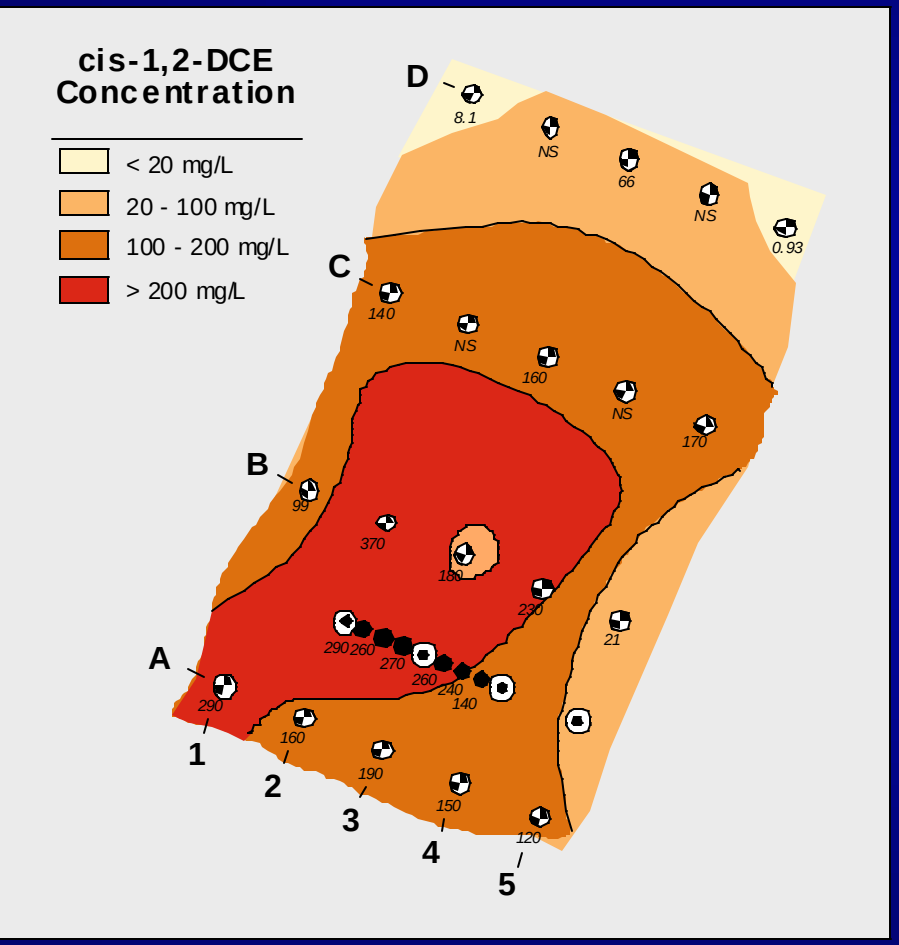


BASELINE



18 Months

18 Month Change in cis-1,2-DCE



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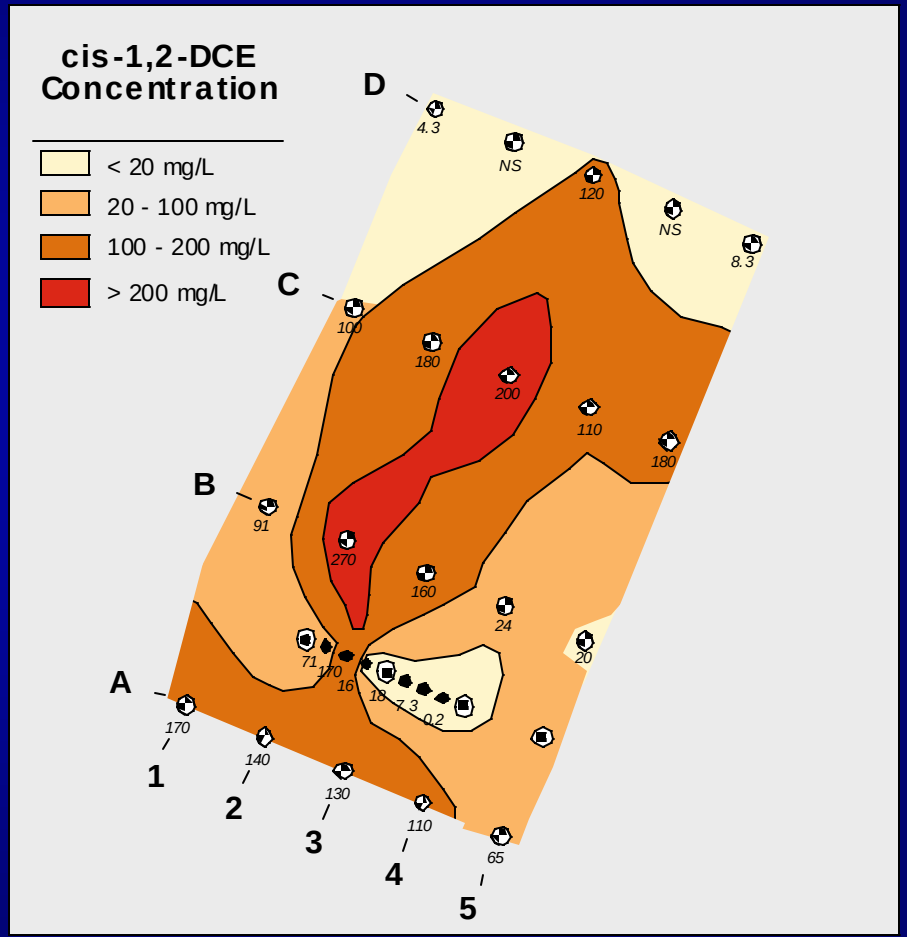
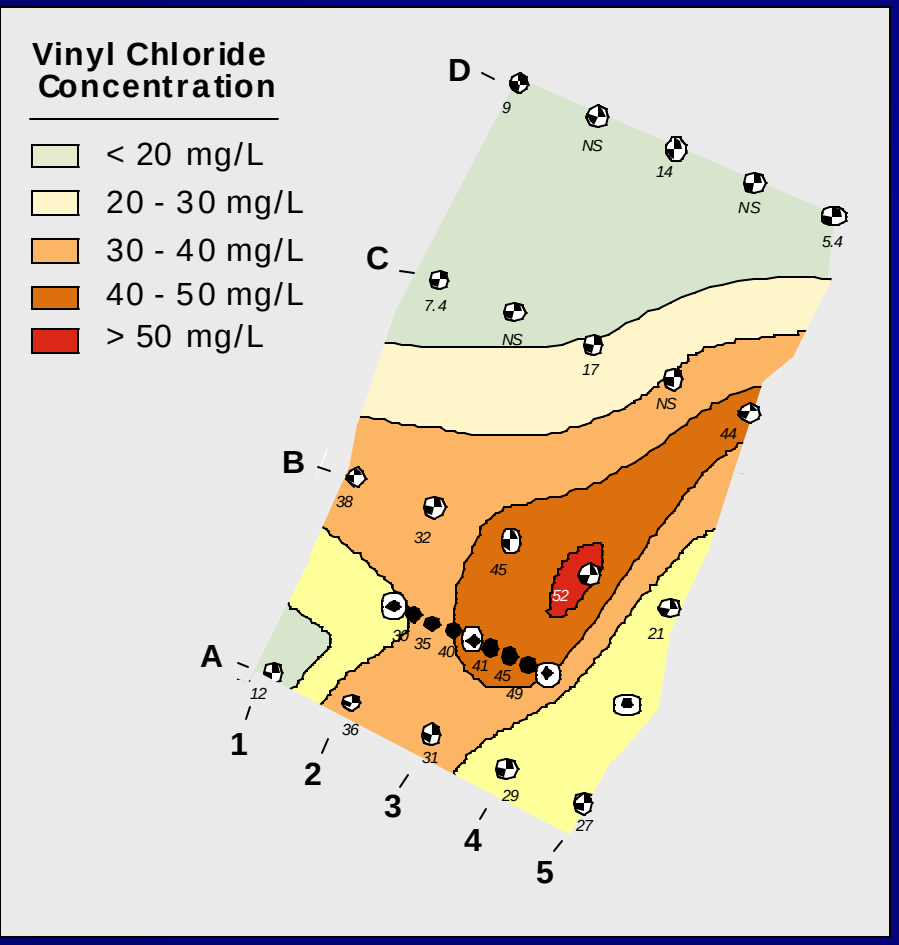


18 Months

18 Month Change in Vinyl Chloride



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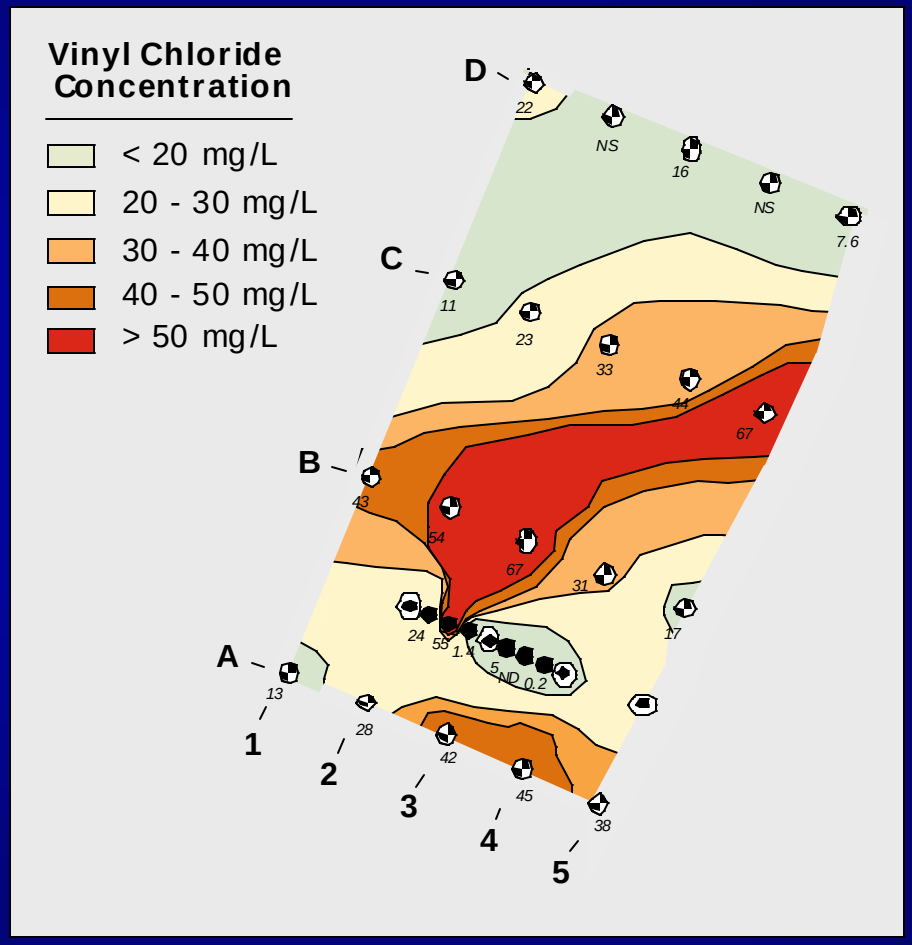
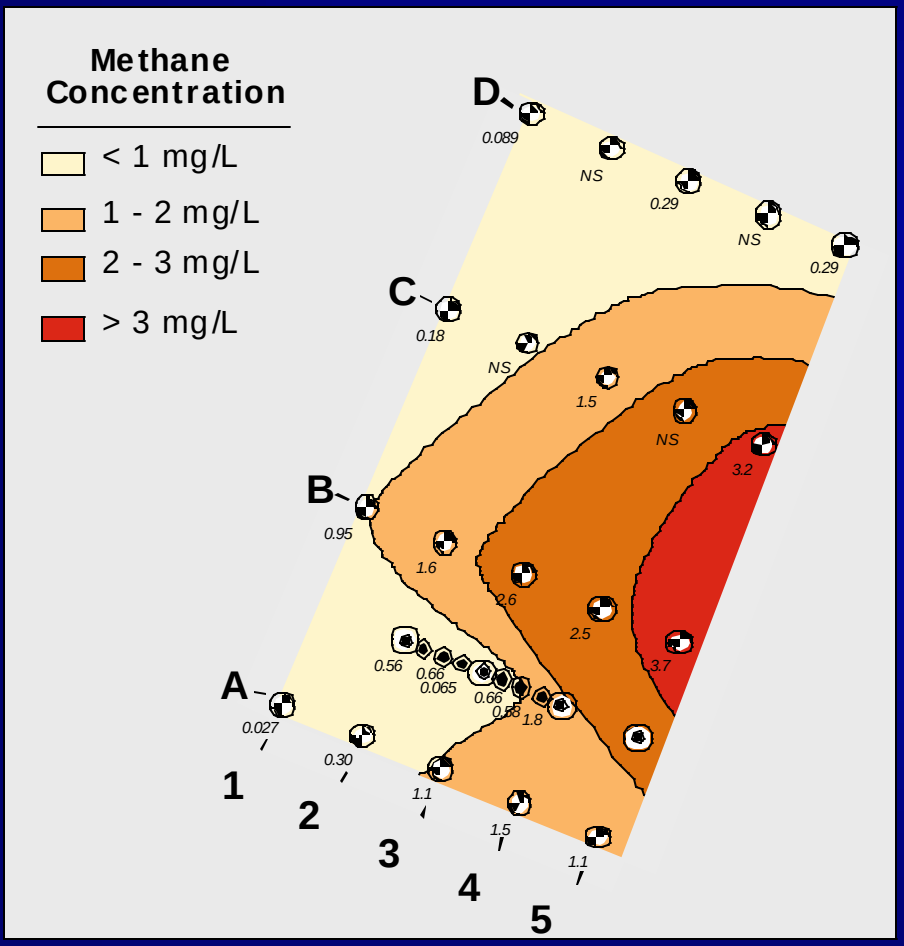
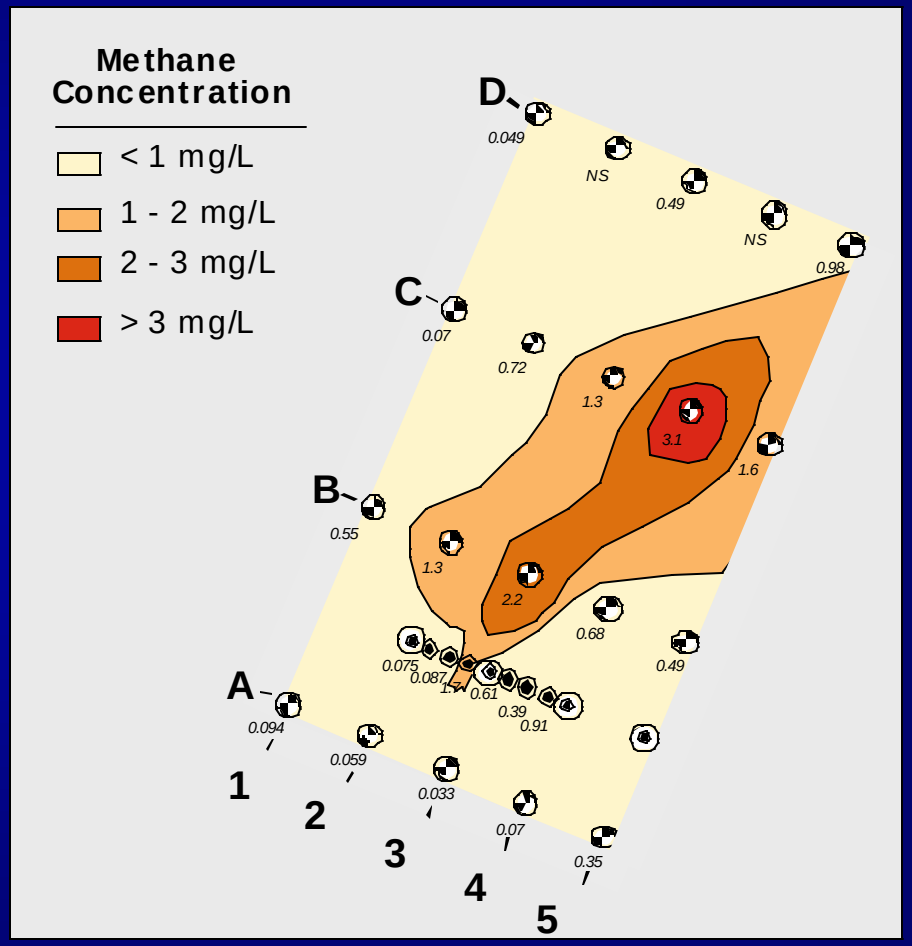


18 Months

18 Month Change in Methane



BASELINE



18 Months

Cape Canaveral Hydrogen Biosparge

Concentration Change Over 18 Months (mg/L)

Distance from Sparge	*change in conc. (mg/L)*			
	Test Zone		Control Zones	
	(H_2: 3-6 ft)	(H_2: 15 ft)	(N_2: 15 ft)	(N.A.: 25 ft)
Chlorinated Ethenes	- 274	-142	-5	-42
	(-95%)	(-49%)	(-12%)	(-20%)

Cape Canaveral Hydrogen Biosparge

CONCLUSIONS

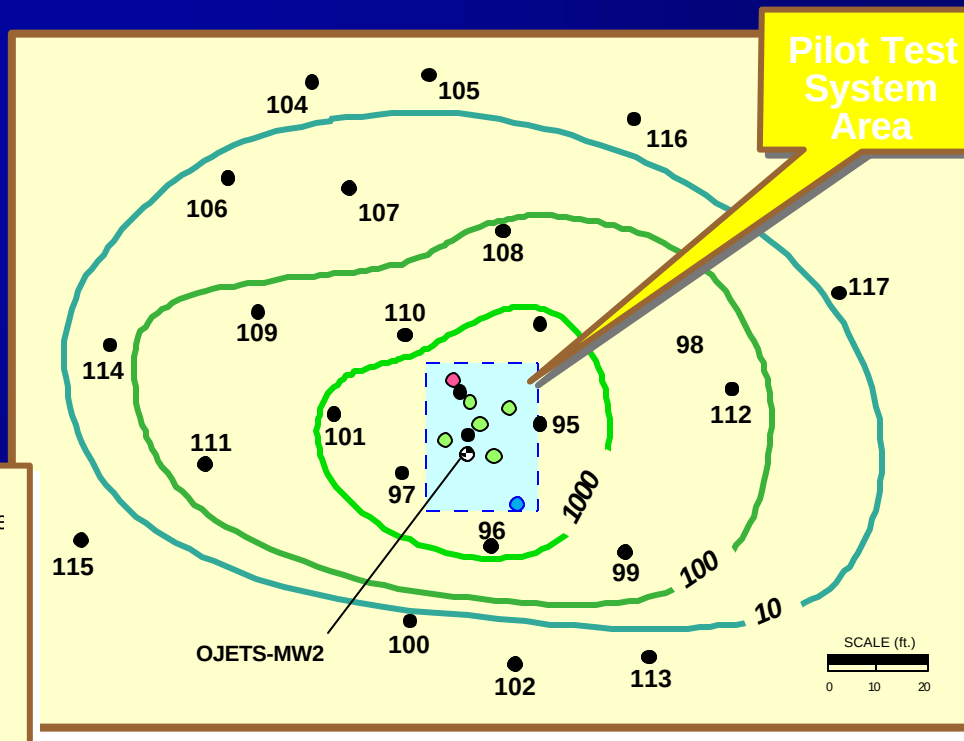
- Tracers show biological consumption of hydrogen
- Significant reduction in TCE, DCE, VC over 18 months
- P/D ratios indicates biodegradation, not volatilization
- Methane competition not observed
- Direct radius of influence: 5 - 10 ft; indirect 15 ft+

Pilot Test 2: Objectives

- To test the efficacy of dissolved hydrogen recirculation as an electron donor to promote reductive dechlorination of TCE-impacted groundwater

Site Description

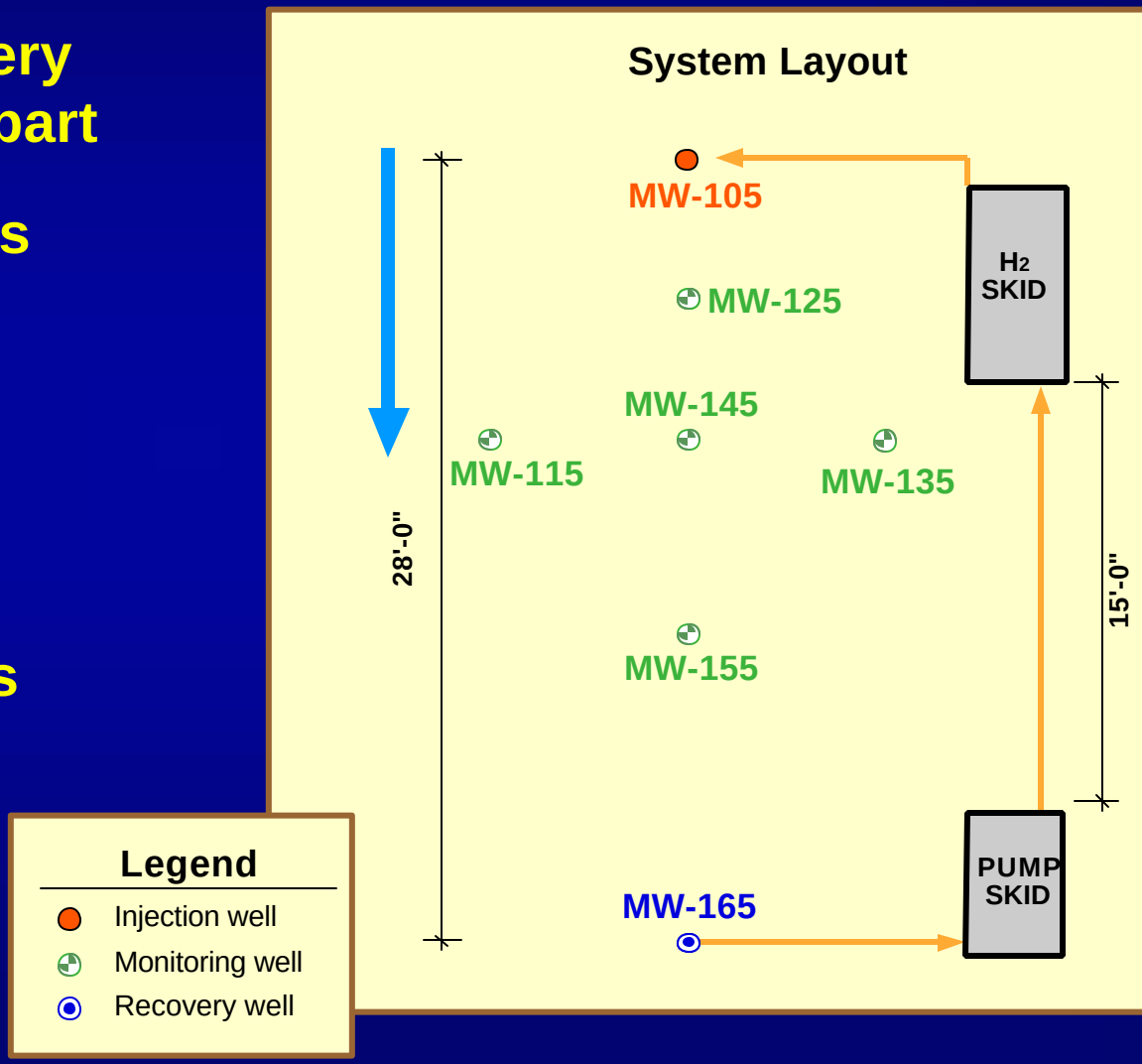
- Hydrogen pilot test performed at Old Jet Engines Test Site (OJETS), Offutt AFB, Nebraska
- Hot spot near OJET-MW2 resulted in a 120 x 160 ft TCE plume
- 2.3 mg/L TCE, 0.15 mg/L c-DCE maximum concentrations at test location
- Low levels of PCE and vinyl chloride



Direct- push sample location and numbe
Monitoring Well Location
– 10 – Total CAH isoconcentration contour
AFCEE Monitoring Well Location
AFCEE Recovery Well Location
AFCEE Injection Well Location

Monitoring Well Network

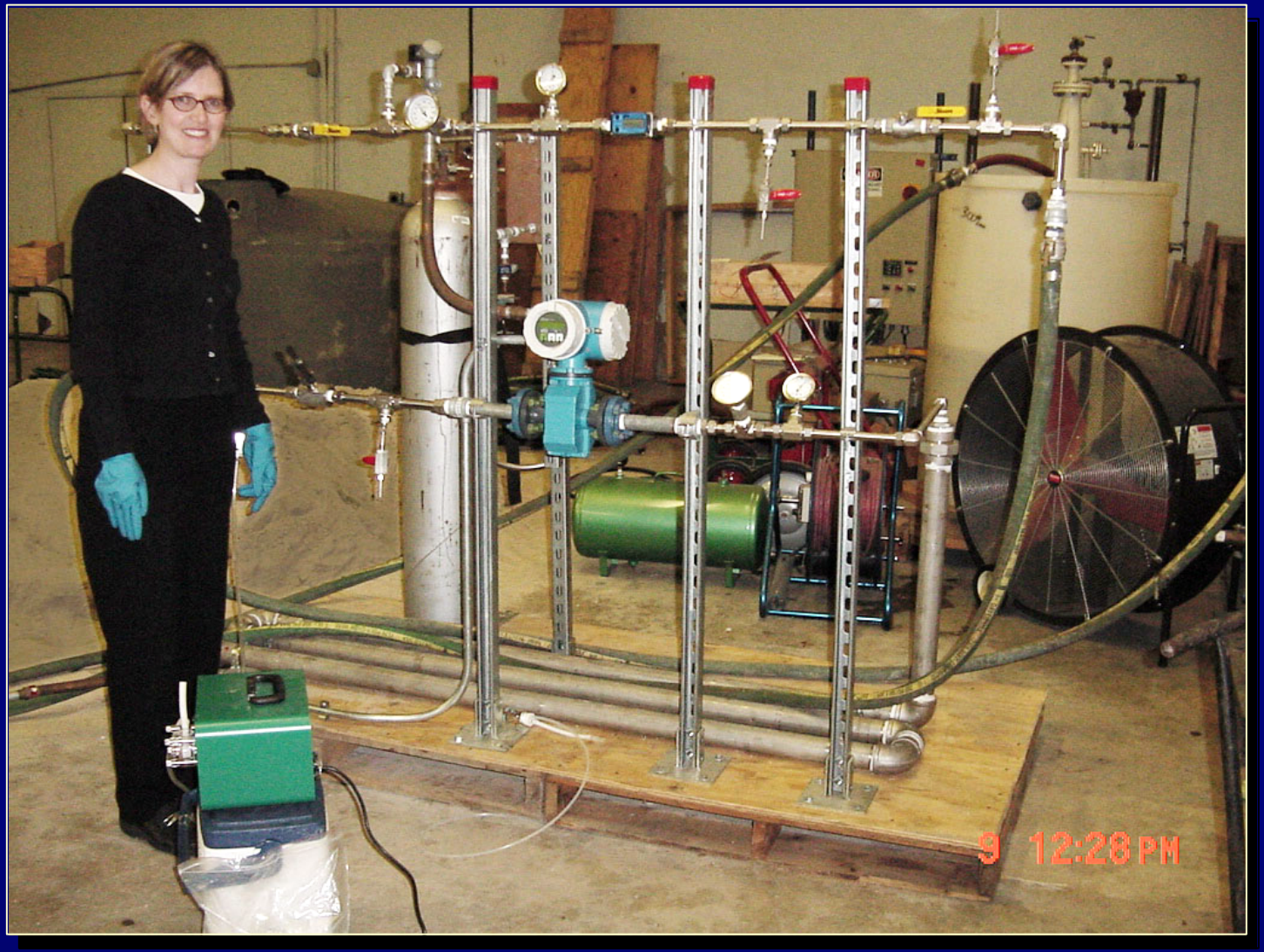
- 1 injection and 1 recovery well (4”) spaced 28 ft apart
- Five 2” monitoring wells within the test area (24 ft deep, screened 12 - 22 bgs)
- Wells sampled at t = 0, 4, and 6 months; 3 more sampling events planned
- Test to be conducted from 4/02 to 8/03



Recirculation System Description

- Pump extracts groundwater at 0.4 gpm
- Groundwater amended with H_2 at 20 ml/min at 10 psig
- H_2-laden water passes through static mixer and 24 ft of 2” pipe to enhance mixing
- H_2-laden water injected down injection well

System Testing Prior to Field Installation



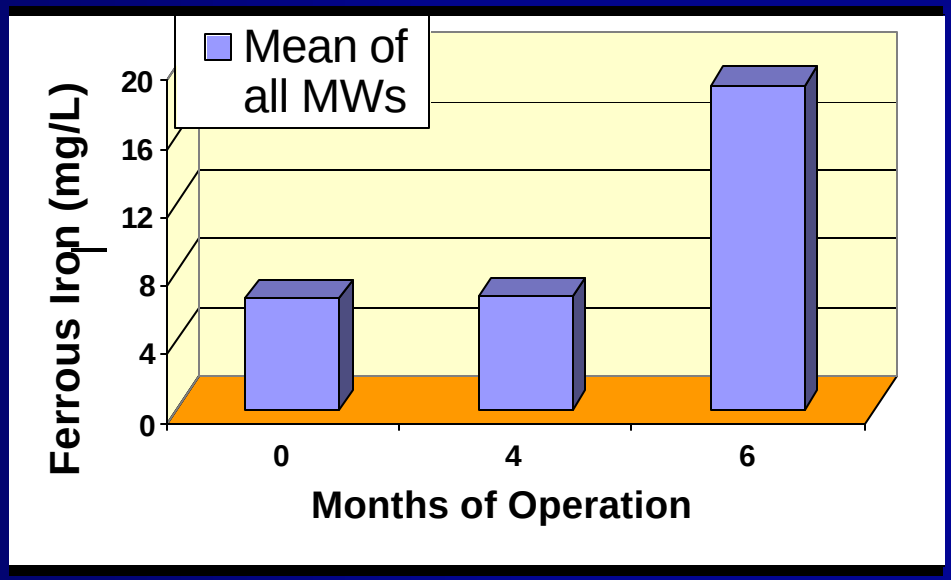
System Installation

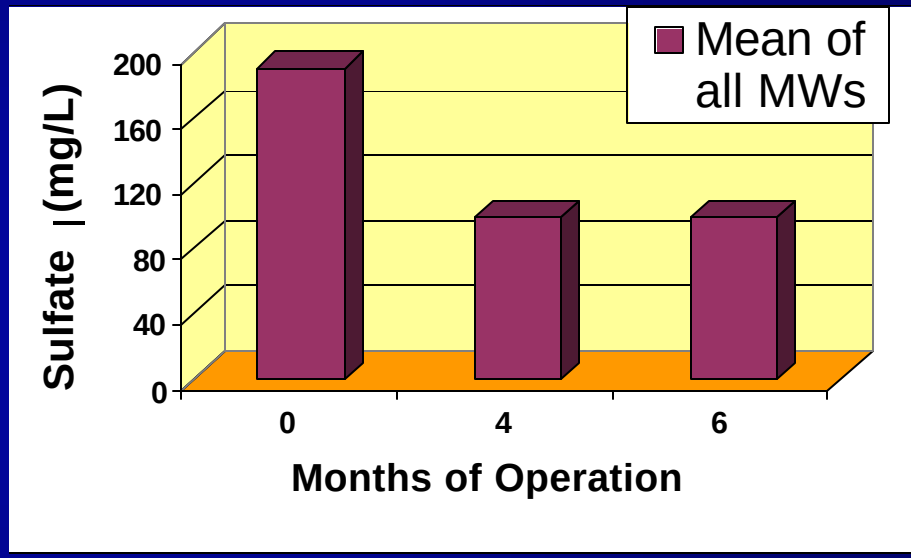
Results:
Dissolved Oxygen and Redox Potential

- D.O. depressed due to consumption of hydrogen and oxygen by aerobic bacteria
- Depressed D.O. and ORP creates conditions for reductive dechlorination

	MONTHS OF OPERATION		
	0	4	6
Mean ORP (mv)	-101.7	-124.2	-180.7
D.O. (mg/L)	0.7	0.1	0.3

Results: *Iron & Sulfate Reduction*

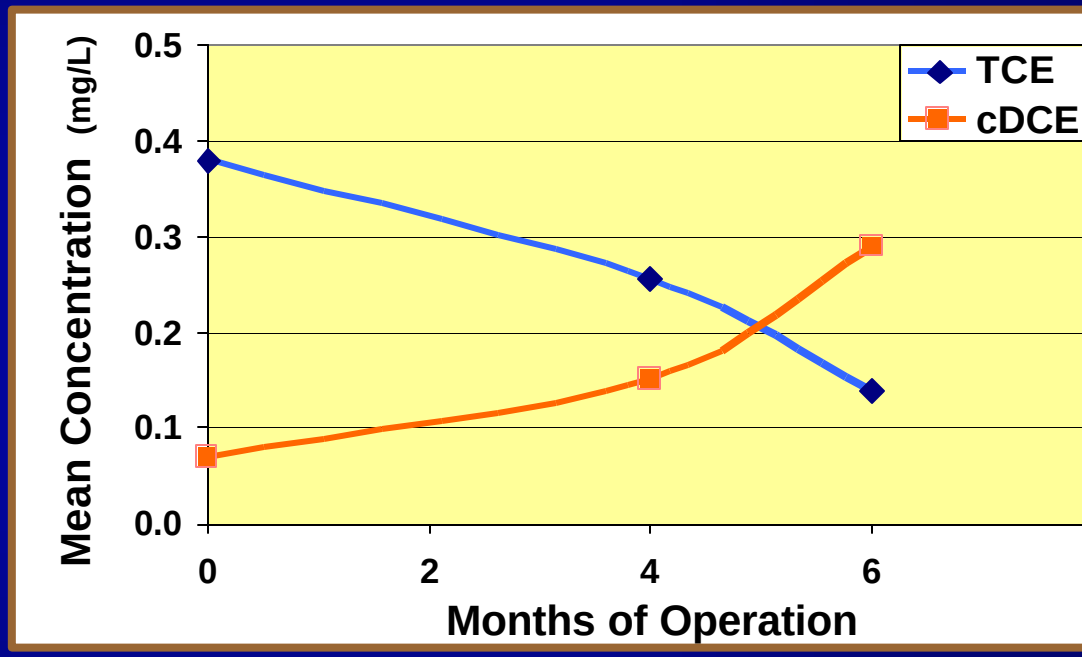




Ferrous iron production and sulfate reduction indicate decreasing redox conditions over time due to the addition of hydrogen.

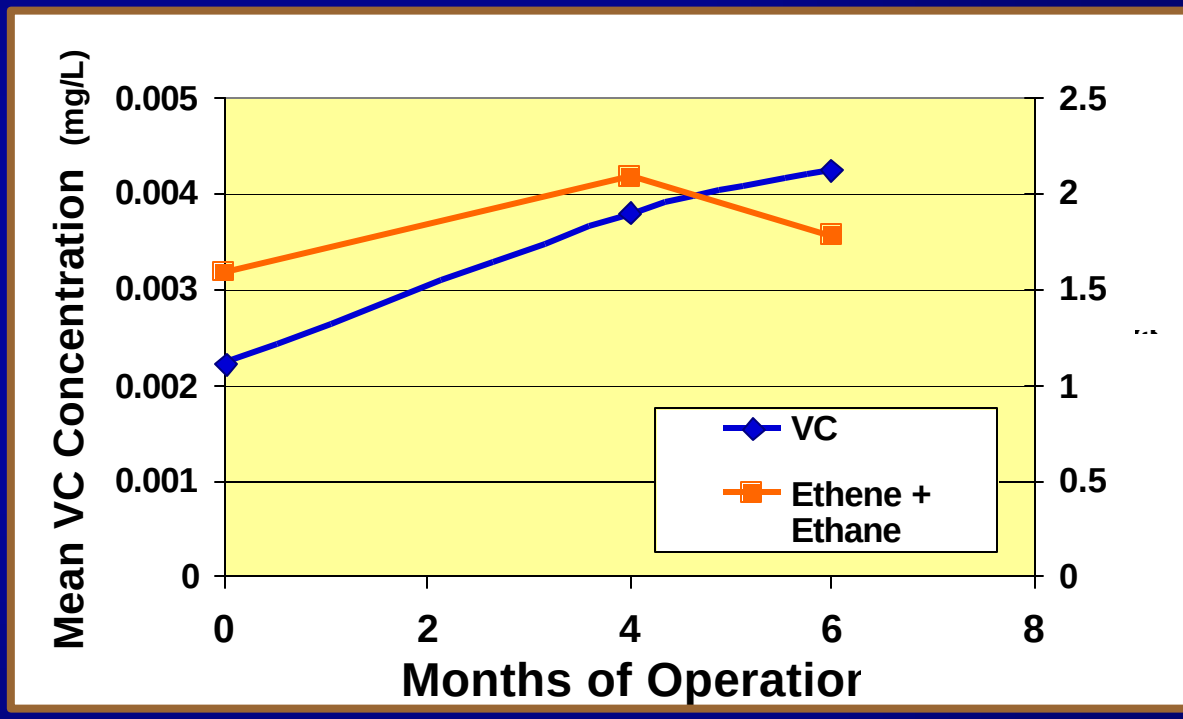
Results: *TCE and c-DCE*

- Mean TCE Conc. at t = 0
  = 0.38 mg/L
- Mean TCE Conc. at t = 6 months
  = 0.14 mg/L
- Mean % TCE degraded
  = 63%



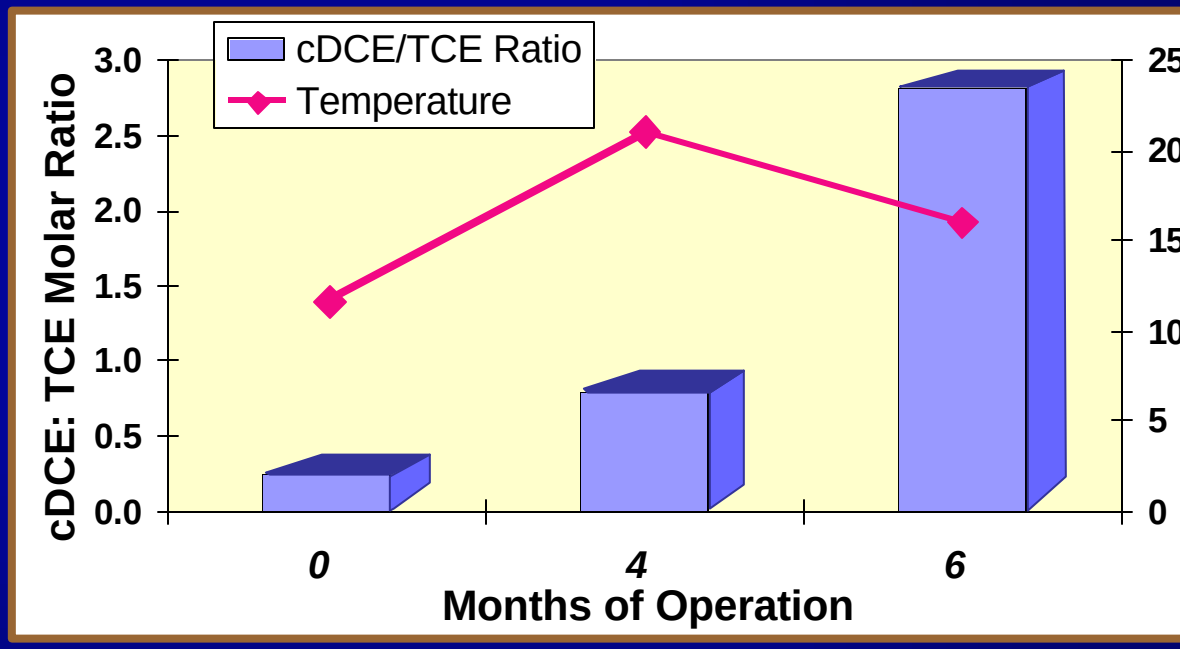
Results: *Vinyl Chloride, Ethene+Ethane*

- Low levels of VC produced, but < 5 µg/L.
- Ethene and ethane indicate complete dechlorination possible, but concentrations are very low

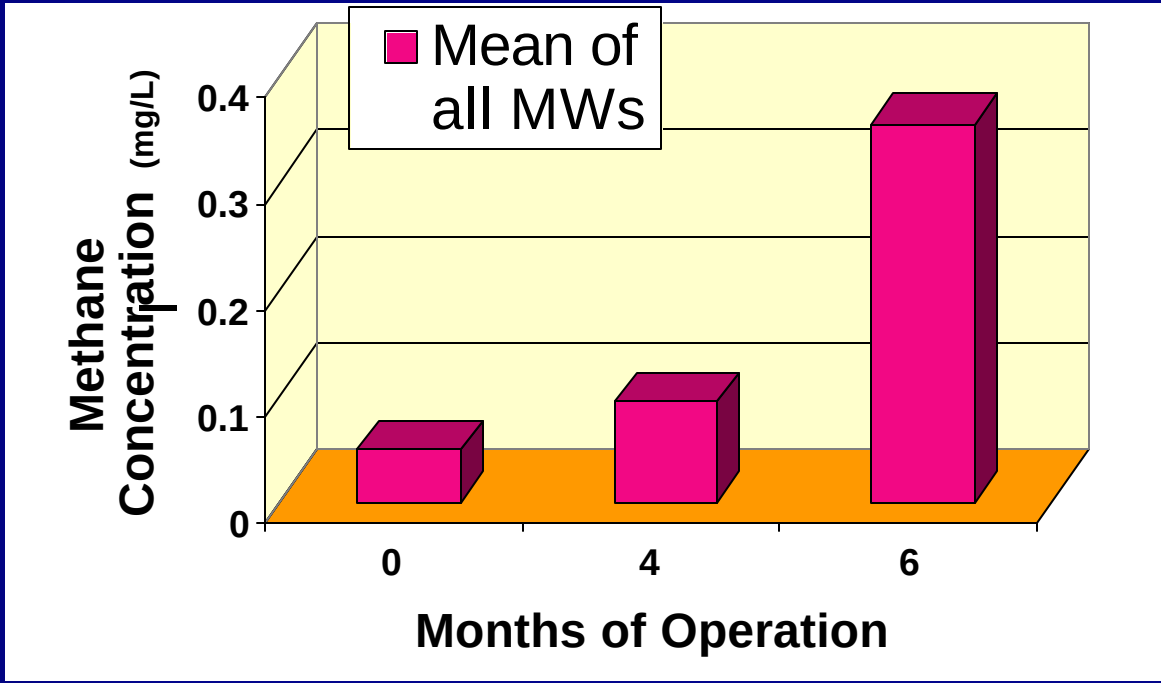


Results: *Ratio to c-DCE to TCE*

- **Large increase in c-DCE:TCE ratio after six months**
- **Ratio increases even though temperature decreased**



Results: *Methane*



- **Some methane production observed after 6 months, but concentrations low and no impact on TCE degradation**

Conclusions

- Dissolved hydrogen is capable of depressing D.O. and ORP in aquifer
- Hydrogen stimulates reductive dechlorination
- Significant TCE removal is possible (63% after 6 months), with minimal VC production
- To date, most of the TCE has been transformed to c-DCE
- Production of low concentrations of methane does not impair TCE degradation
- Performance of system improving over time even though temperature decreasing

Acknowledgments

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